The Carbon Balance Observatory (CARBO) Instrument for Space-based Observation of Greenhouse Gases

Shannon Kian Zareh, Charles E. Miller, J. Kent Wallace

Jet Propulsion Laboratory, California Institute of Technology

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The CARBO Team

- Charles Miller (PI)
- J. Kent Wallace
- Yuri Beregovski
- Mayer Rud
- Randy Bartos
- Jim McGuire
- Tom Pagano
- Dan Wilson
- Cynthia B. Brooks – UT Austin
- Dan Jaffe – UT Austin
- Andre Wong
- Didier Keymeulen
- Peter Sullivan
- Elliott Liggett
- Michael Bernas
- Amy Mainzer
- Annmarie Eldering
- Dejian Fu

Overview of Presentation

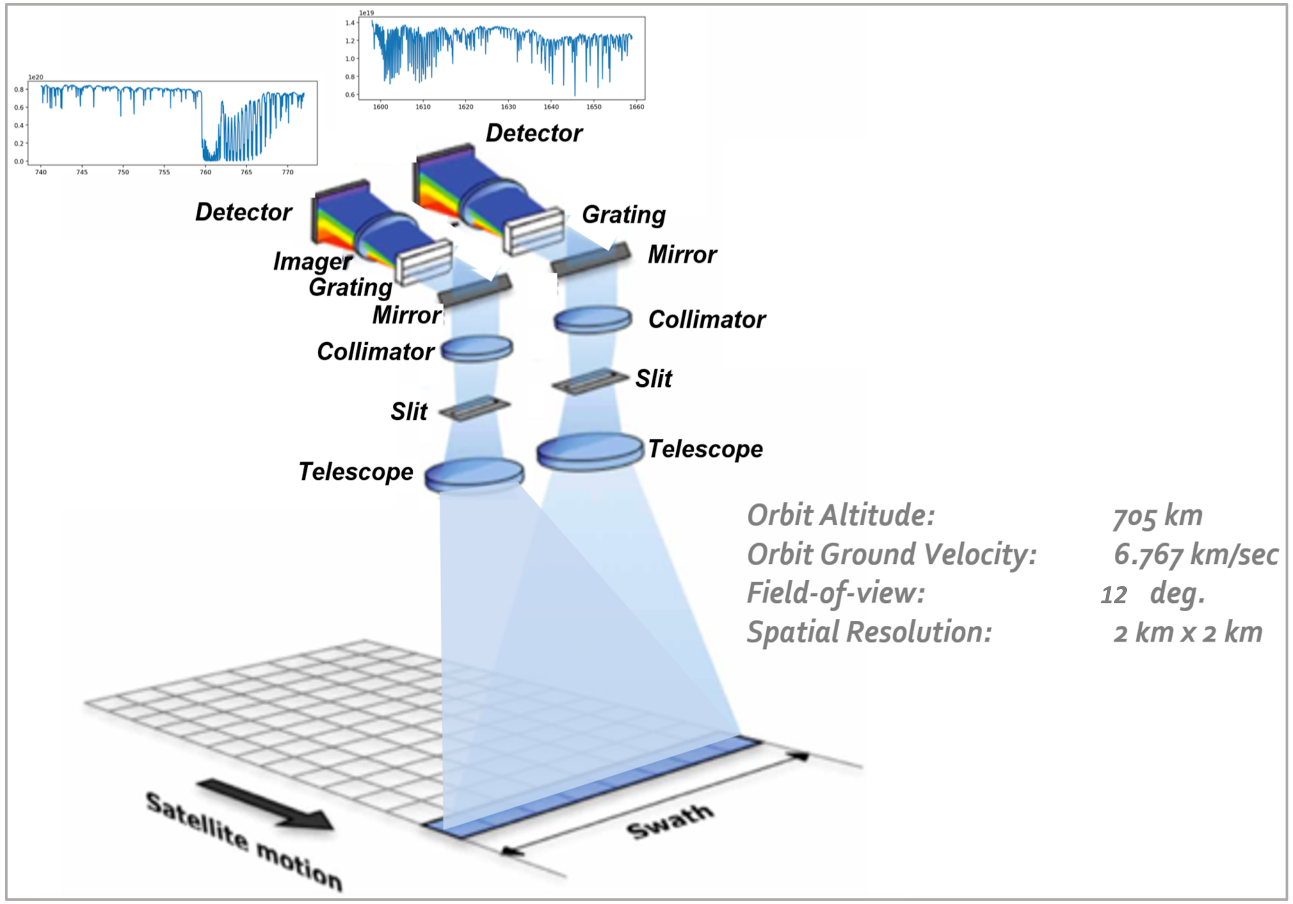
- Programmatic overview
- CARBO instrument concept
- Instrument architecture
- Key technologies
  - Immersion gratings
  - Polarization sensing
  - Large format CHROMA-D/GeoSnap focal plane arrays
- Instrument radiometric performance estimate
- Summary and conclusion

Programmatic Overview

- Funded by Instrument Incubator Program (IIP)
  - NASA's Earth Science Technology Office (ESTO)
- Institutions:
  - Jet Propulsion Laboratory
  - University of Texas at Austin
  - Caltech
- Goal:
  - Develop a new, more capable suite of instruments to measure the green house gasses for better understanding of carbon climate.
  - Advance new technology immersion gratings and modular instrument architecture.

CARBO Instrument Concept

- Wide-FOV imaging spectrometer
  - FOV: 12 degree with 2k x 2k Geosnap
  - Ground swath: 148 km
- Low Earth orbit (LEO)
- Spatial resolution of 2 km x 2 km
- Weekly revisit rate
- Contiguous spatial sampling
- Adds CH4 and CO to the CO2 and Solar Induced Fluorescence (SIF) measurements pioneered by the Orbiting Carbon Observatory (OCO-2/3)
  - increases ability to disentangle carbon fluxes into their constituent components
- Modular architecture
- New technology
  - Immersion grating
  - CHROMA-D/GeoSnap focal plane array: a large-format, low-noise detector optimized for imaging spectroscopy
  - Polarization sensing

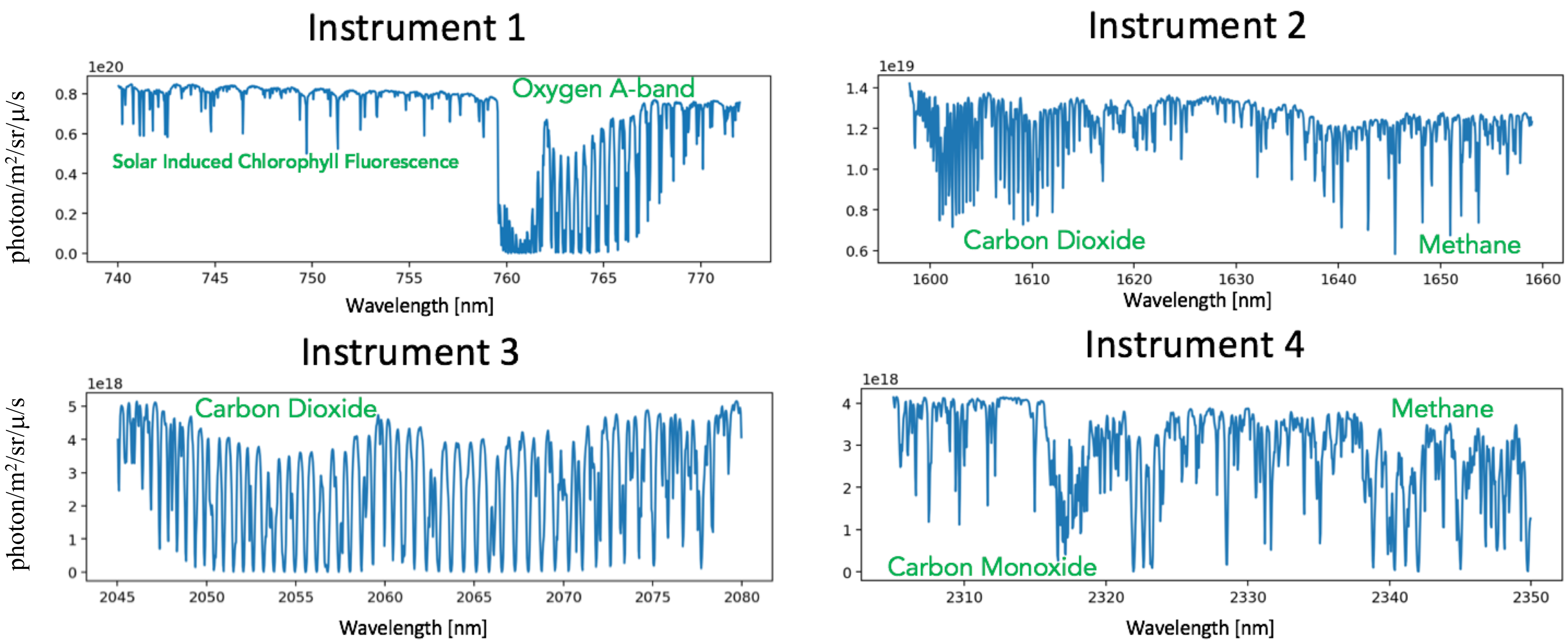


CARBO Design Requirements

CARBO Requirements	Design, Build, Field Test		Design	
	Instrument 1	Instrument 2	Instrument 3	Instrument 4
Spectral Range (nm)	745 -772 ($\Delta\lambda$ = 27 nm)	1598 – 1659 ($\Delta\lambda$ = 61 nm)	2045 – 2080 ($\Delta\lambda$ = 35 nm)	2305 – 2350 ($\Delta\lambda$ = 45 nm)
Measurement Targets	O_2, SIF	CO_2, CH_4	CO_2	CO, CH_4
SNR @ 5% albedo and 50^O SZA	> 300	> 350	> 150	>100
Spectral resolution FWHM (nm) at λ_{ave}	0.05	0.15	0.10	0.12
Spectral Resolving power at λ_{max}	15,440	11,060	20,800	19,583
Required Precision	X_{CO2}<1.5 ppm, X_{CH4}<7 ppb, X_{CO}<5 ppb, SIF <20%			

- Nominal bright case – SNR @ SZA = 35 deg and albedo = 30%
- The SNR case for SZA = 50 deg and 5% albedo is the driving/limiting dark case

Simulated CARBO Instrument Performance

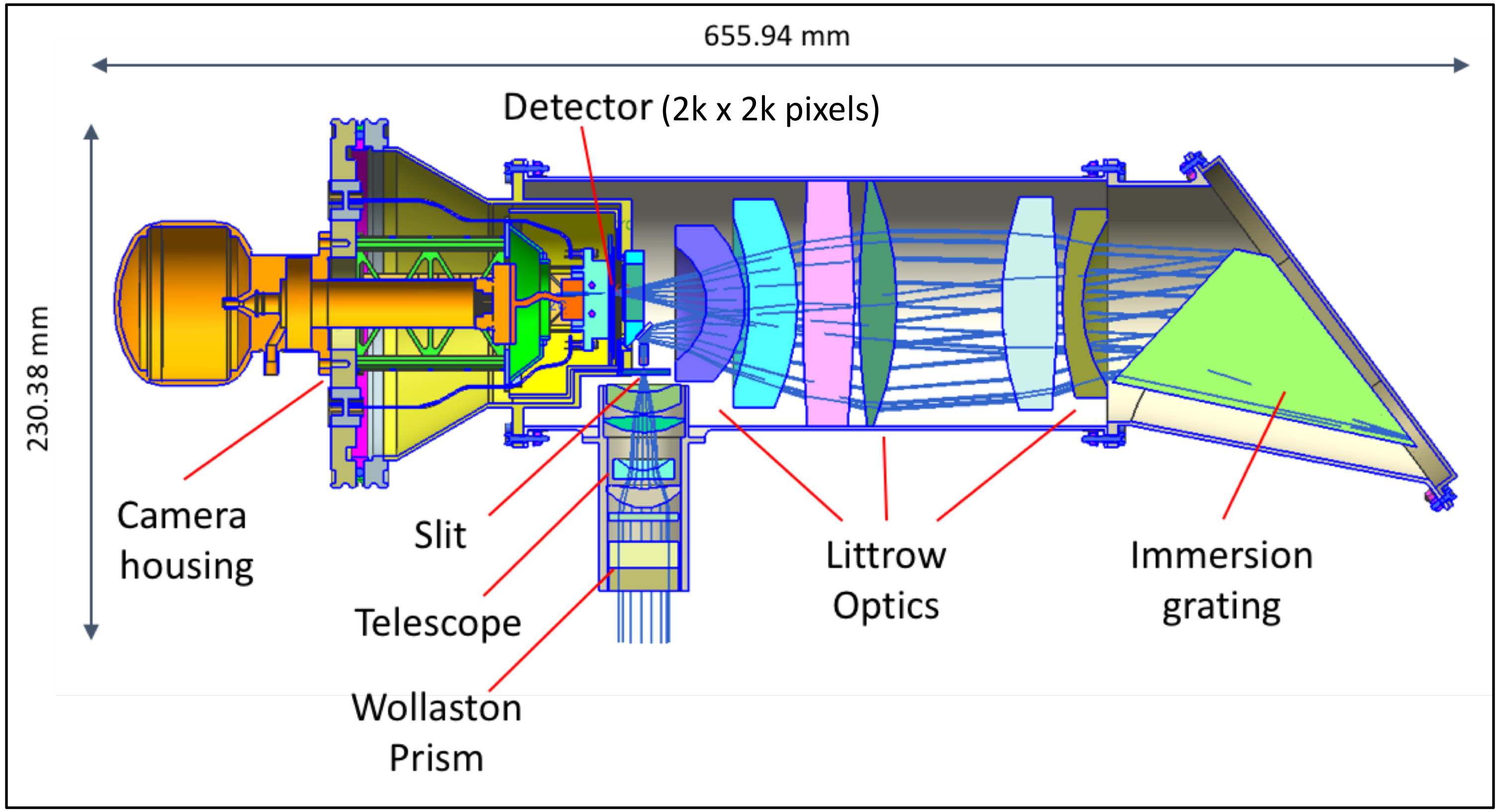


Conceptual **Opto-Mechanical** Layout

Instrument 1

(*745 – 772 nm, Oxygen-A band and SIF Remote Sensing*)

- Telescope aperture diameter: 25 mm
- Telescope focal length: 52.8 mm
- Telescope F/# : 2.11
- Ground Sample Distance: 240 m
- Slit width: 36 um
- Wavelength range : 27 nm
- Spectral Resolution: 0.05 nm
- R = 15,400
- Spectral dispersion: 1080 pixels

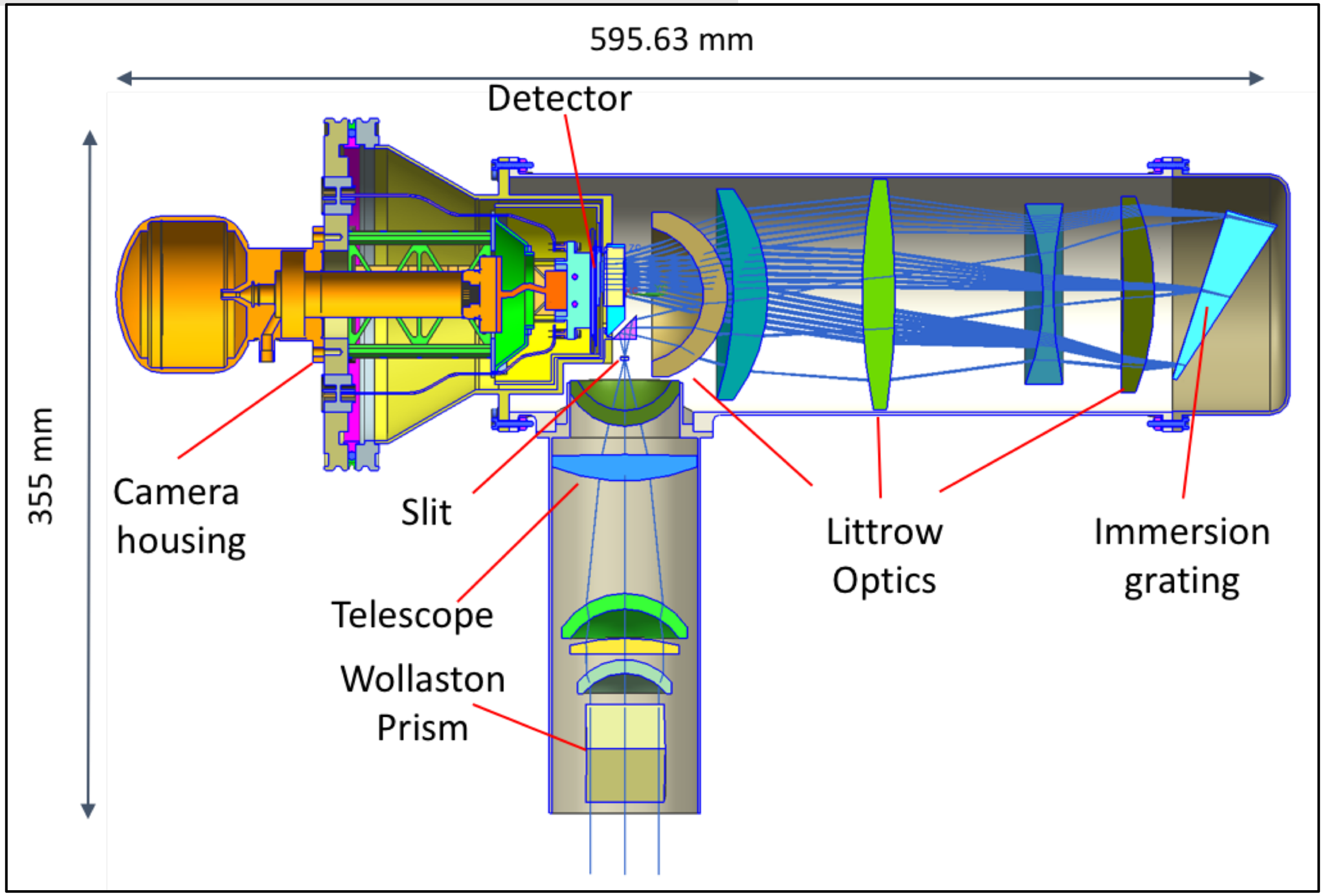


Conceptual **Opto-Mechanical** Layout

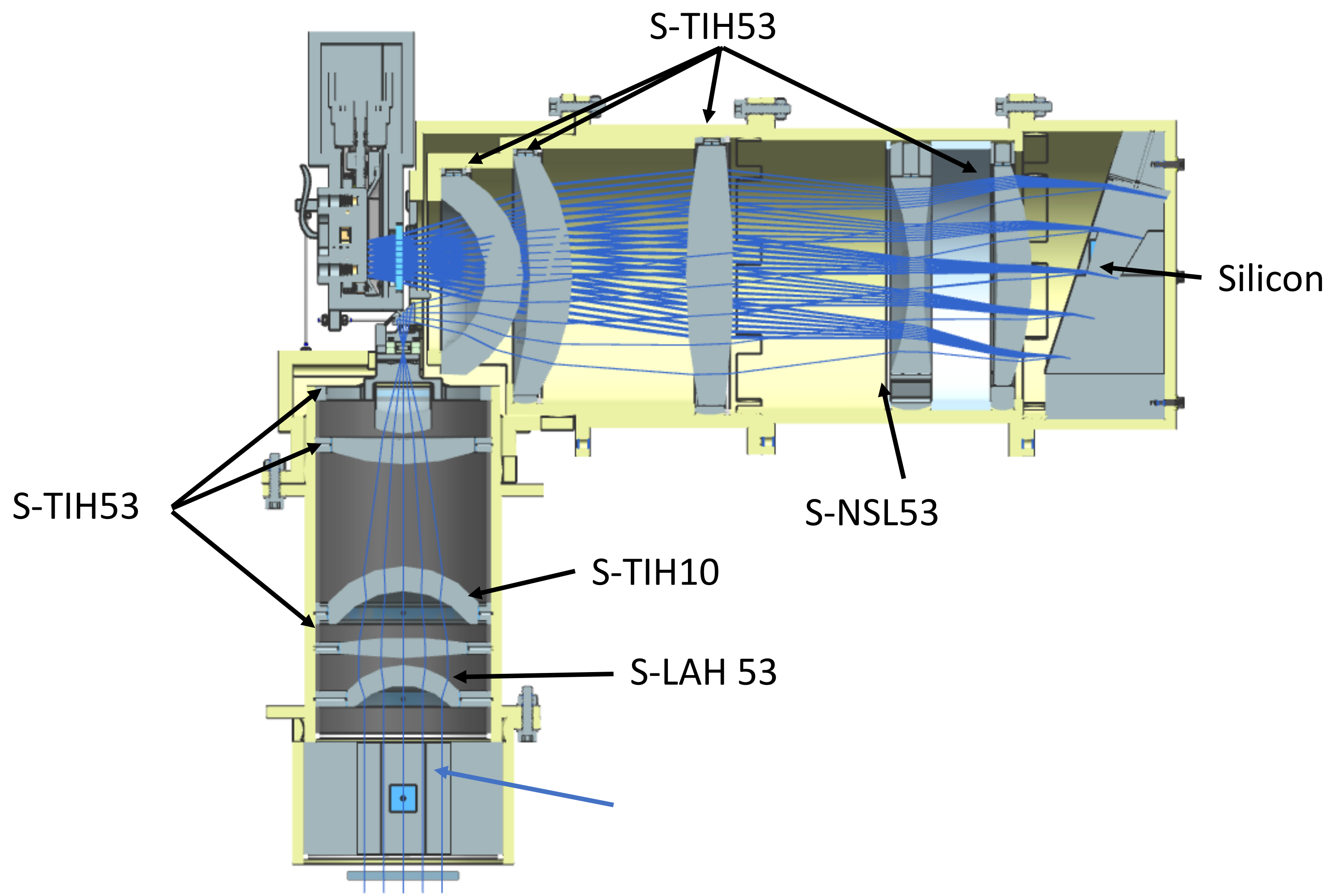
Instrument 2

(*1595 – 1659 nm, CO_2 and CH_4 Remote Sensing*)

- Telescope aperture diameter: 35 mm
- Telescope focal length: 75.18 mm
- Telescope F/# : 2.11
- Ground Sample Distance: 168 m
- Slit width: 36 um
- Wavelength range: 61 nm
- Spectral Resolution: 0.15 nm
- R = 11,060
- Spectral dispersion: 814 pixels



Instrument 2
Optical Design & Optomechanical Packaging

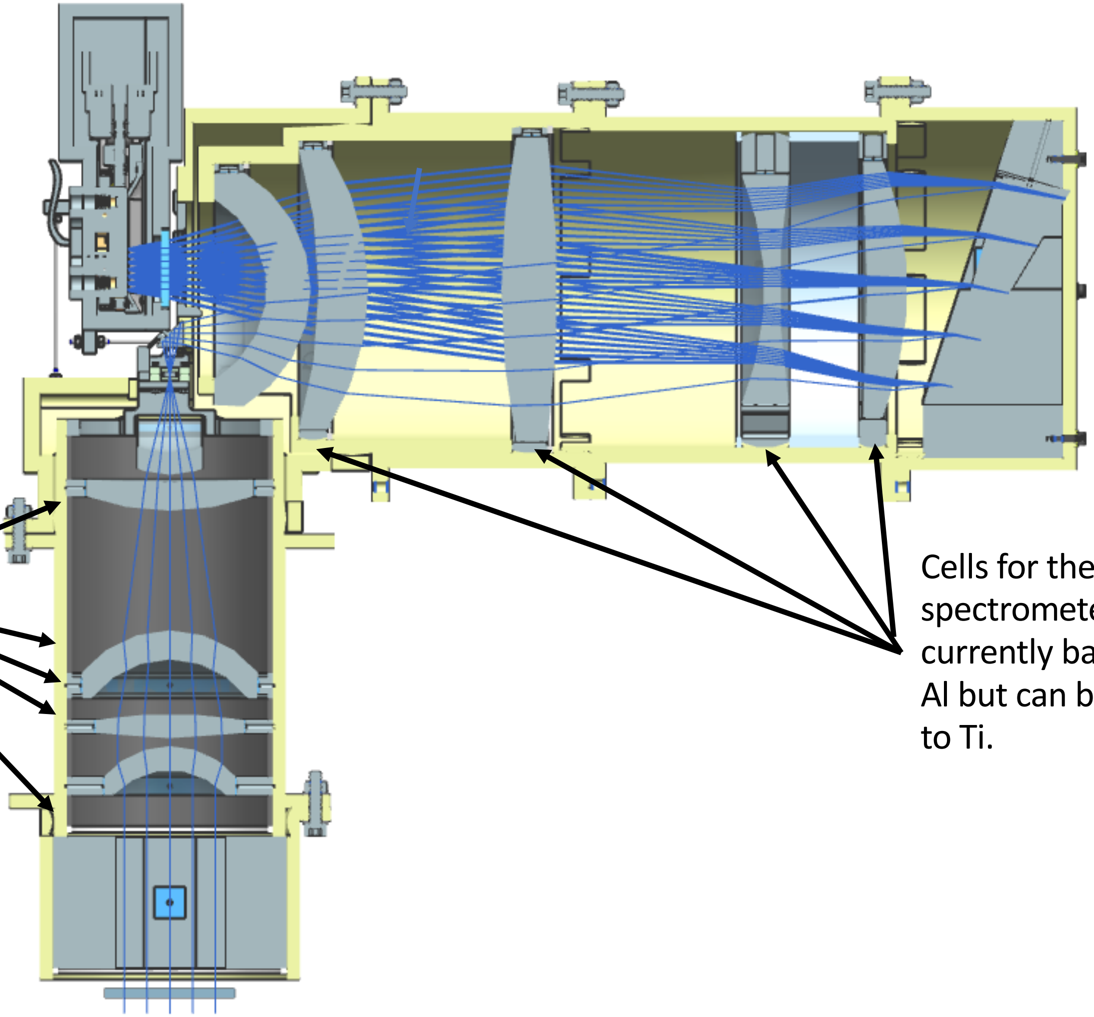


Instrument 2
Optical Design & Optomechanical Packaging

Spacers and retaining rings - Al 6061

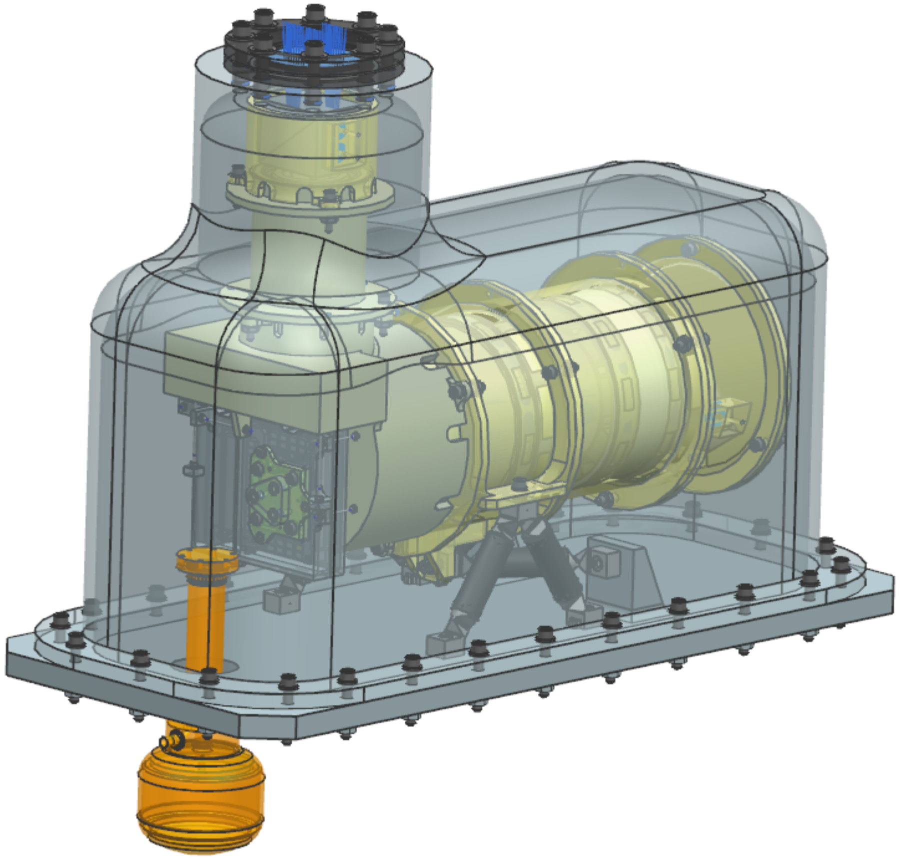
Glue is RTV

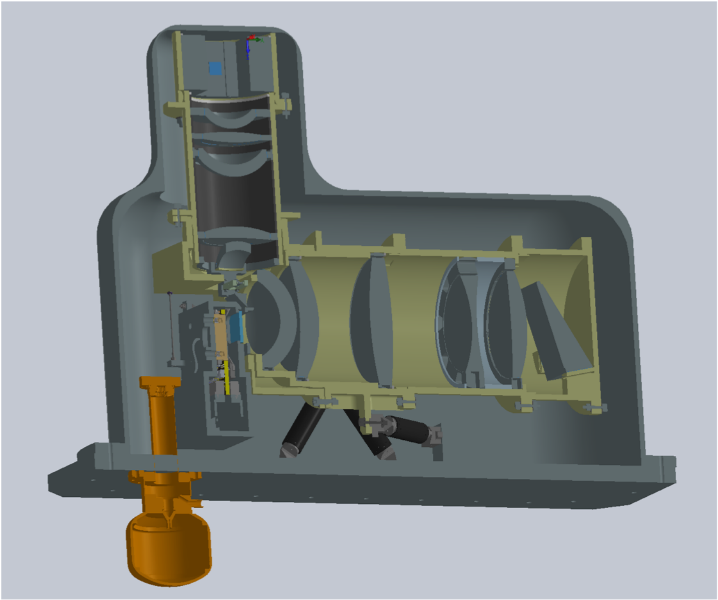
Cells are Al 6061 in Telescope

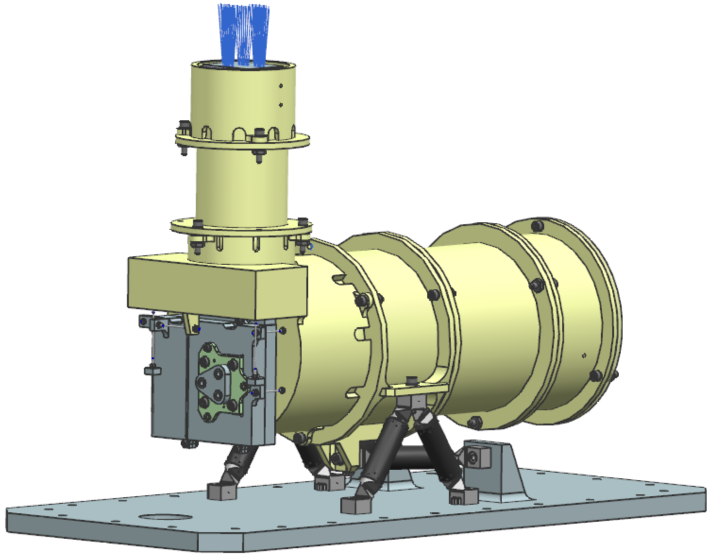


Cells for the optics in spectrometer are currently baselined for Al but can be changed to Ti.

Instrument 2



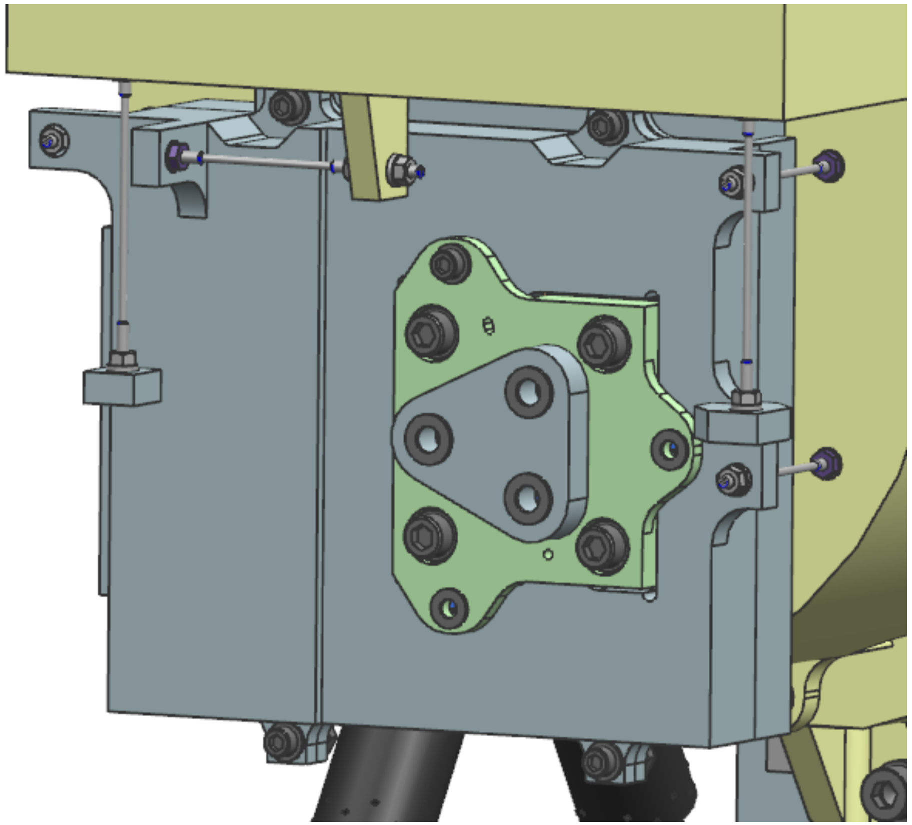


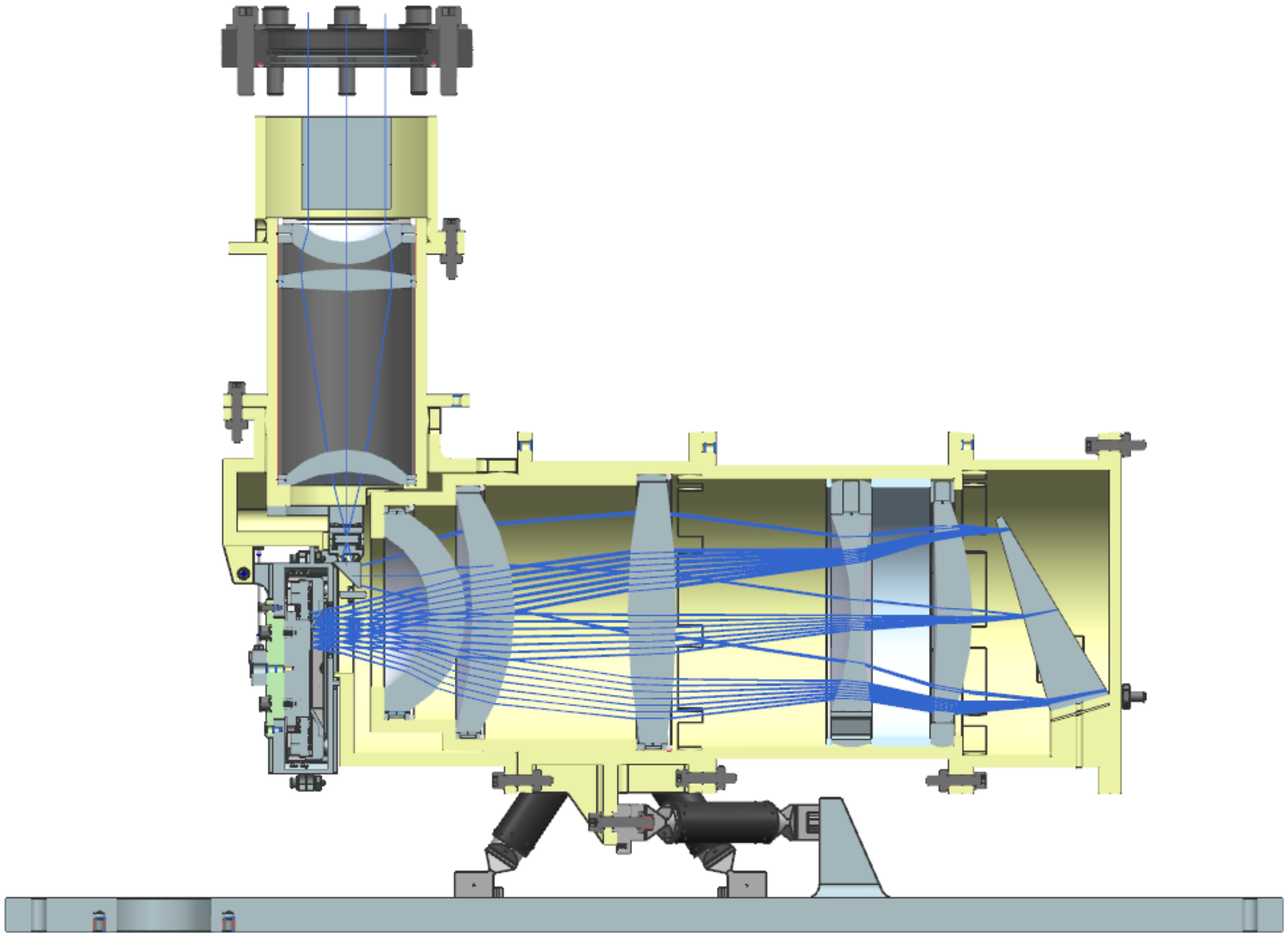


Overall Dimensions: 580 mm X 260 mm X 526 mm

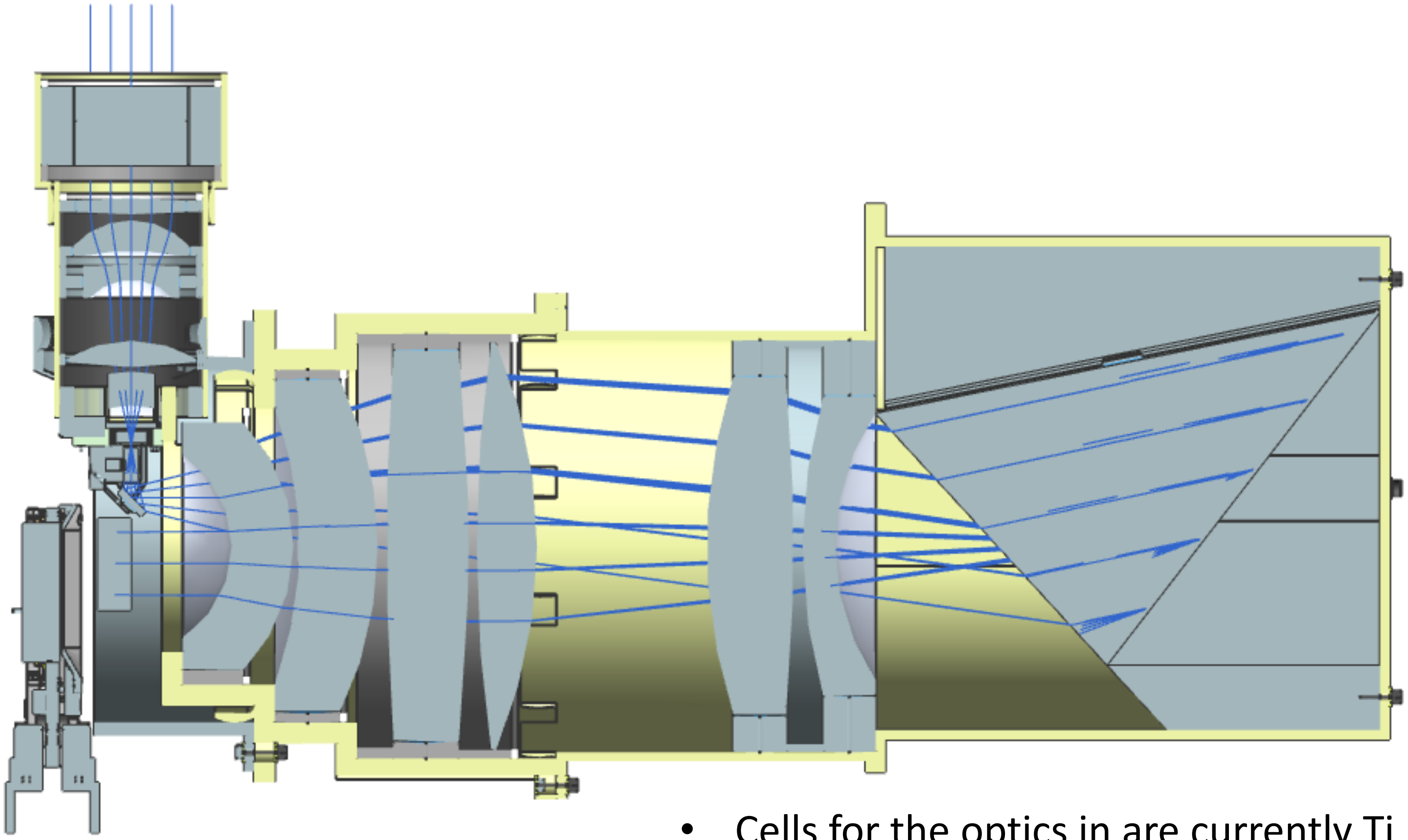
- Preliminary Thermal Model Geometry (4/19/19)

Instrument 2





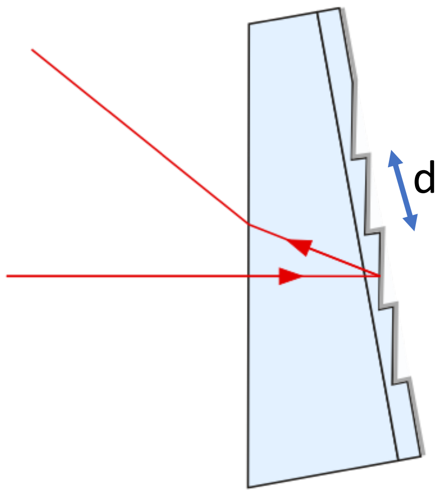
Instrument 1
Optical Design & Optomechanical Packaging



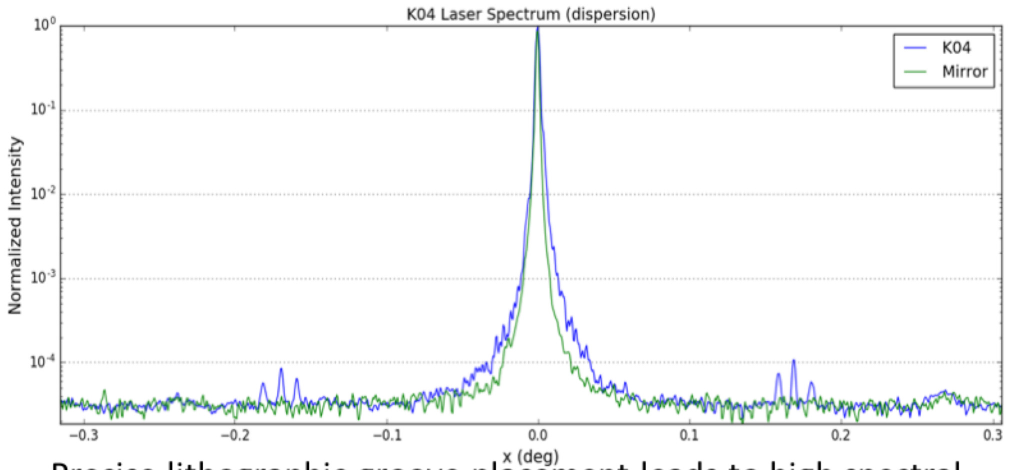
- Cells for the optics in are currently Ti
- Glue is 2216
- Lens Barrel is Al 6061

Key Technologies: Immersion Grating

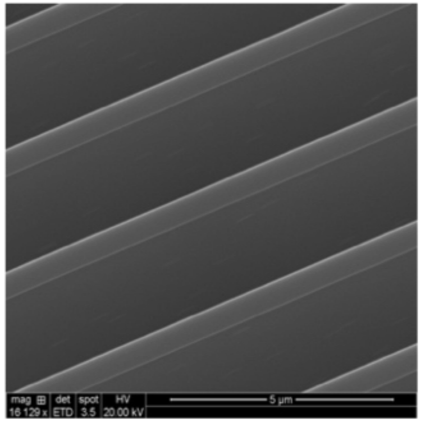
- Si immersion gratings enable CARBO NIR instruments to take full advantage of large format FPAs
- Significantly decreases instrument size
- Up to 15 degree field of view
- Excellent optical performance across entire FPA



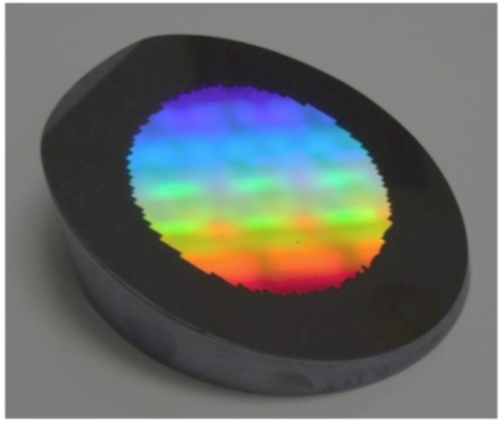
Glass prism with polymer grating



Precise lithographic groove placement leads to high spectral purity.



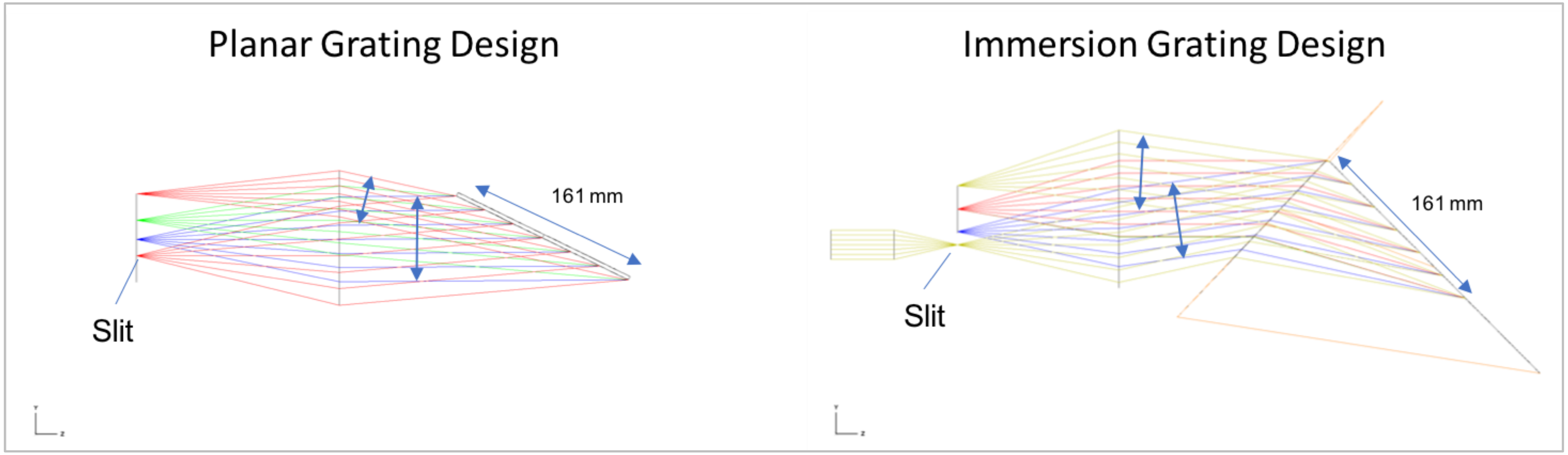
Groove structure



Grayscale E-beam Patterned Grating Etched into Silicon Prism
(Grating diameter 55 mm, Prism AR-coated on non-grating side)

Immersion Grating Correction of Anamorphic Compression

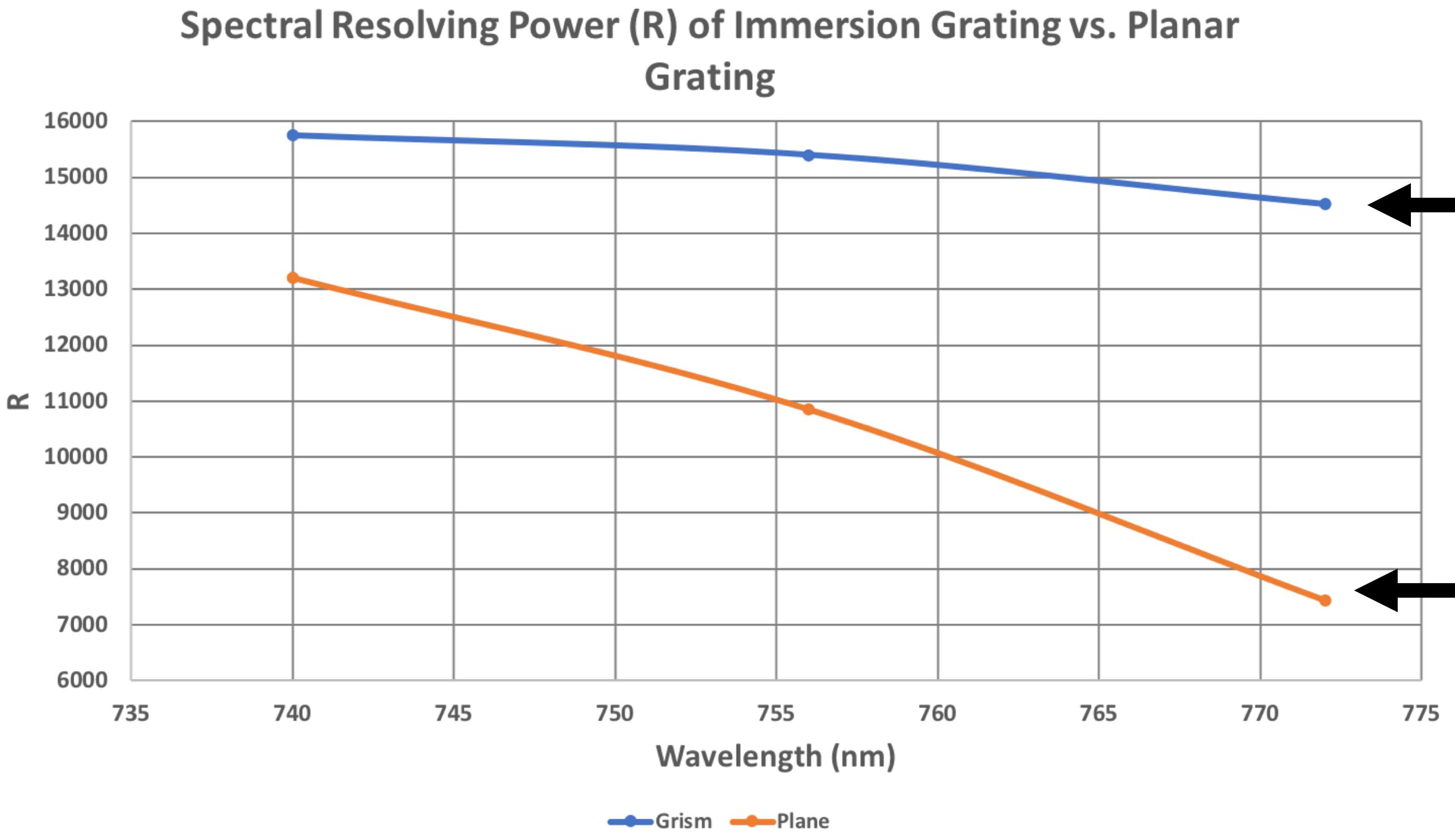
Immersion Grating Benefit: Reduction in Anamorphic Compression



- A planar grating causes anamorphic beam compression
- An immersed grating can be designed so that the anamorphism is largely compensated by the prism
- Anamorphic correction allows for more symmetric PSF over wavelength, which enables more uniform sampling over the detector

Immersion Grating and Spectral Resolving Power

Immersion Grating Benefit: Improvement in Resolving Power Uniformity Across Wavelength



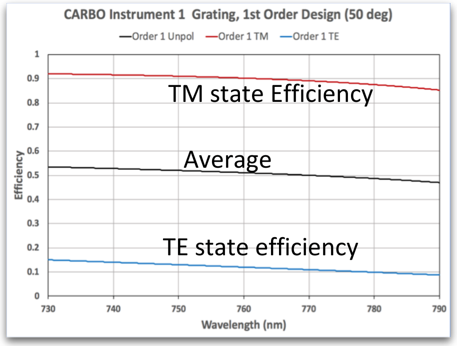
Grating length: 161 mm

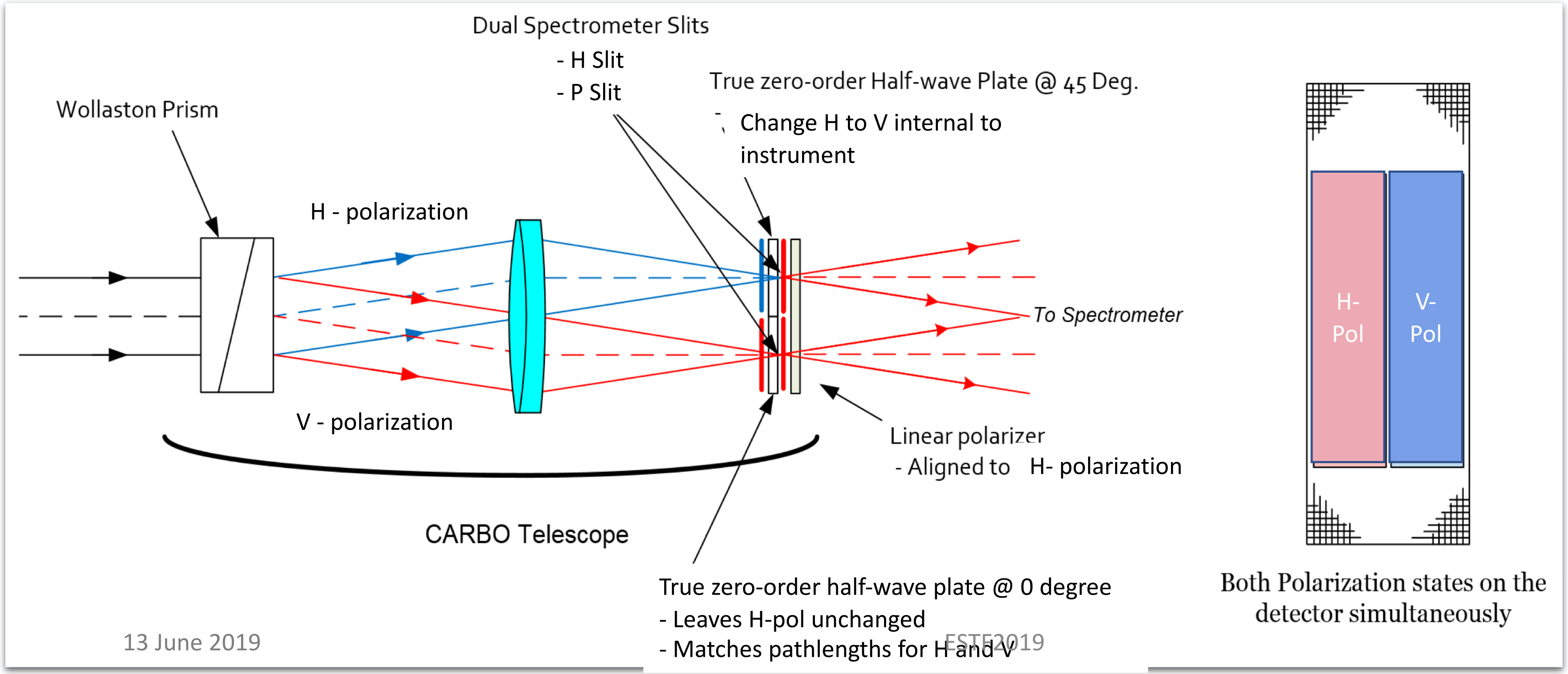
Immersion grating: Spectral resolving power varies by 1.08

Planar grating: Spectral resolving power varies by 1.8

Key Technology: Simultaneous Polarization Sensing

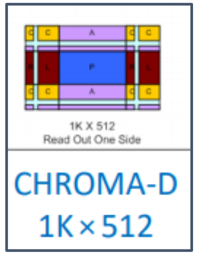
- In general, all gratings are sensitive to polarization states: different grating efficiency for each polarization state → lose photons
- CARBO utilizes an optical design that is insensitive to polarization state, with high grating efficiency
- Enhances sensitivity to surface polarization effects, aerosol composition (better constraints on scattering parameters) and better discrimination of atmospheric and surface scattering.

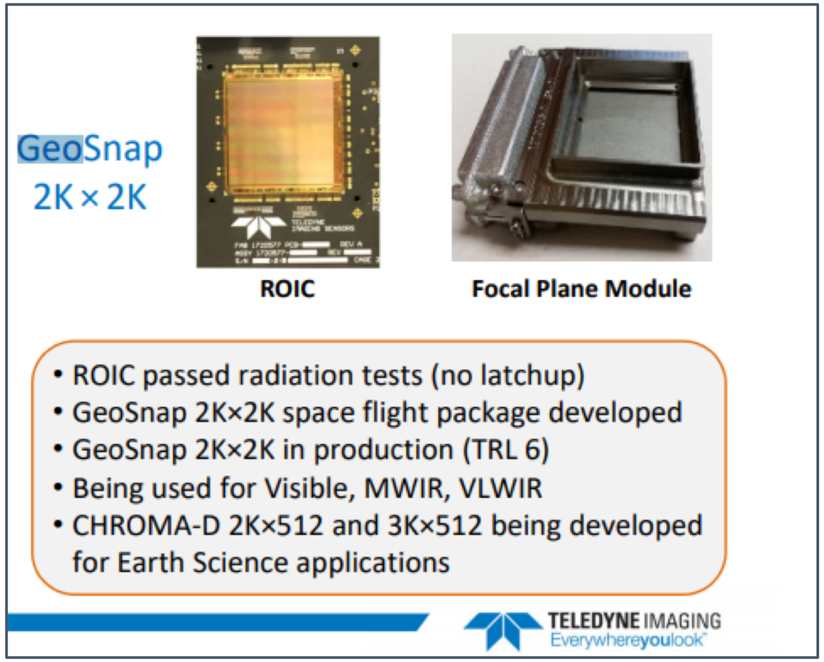




New Technology: Large Format FPA CHROMA-D/GeoSnap

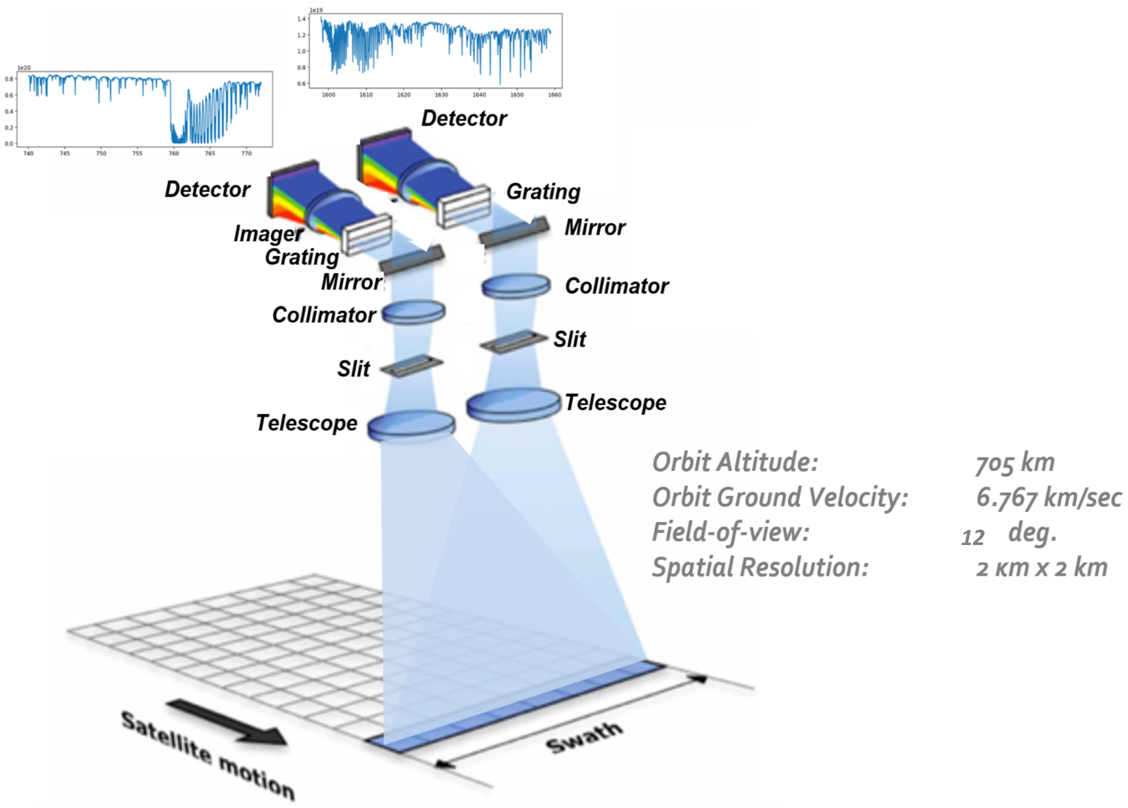
- Latest infrared focal plane technologies from Teledyne Imaging Sensors (TIS)
- 18 um pixel pitch HgCdTe detector hybridized to digital ROIC
- Variable array sizes of 2k x 500 (Chroma-D) and 2k x 2k (GeoSnap)
- Unit cell with 2 gains / full well
  - 100 ke- and 1Me- or 180 ke- and 2.7 Me-
- On-chip digitization
  - without the need for complex analog-to-digital electronics supporting the FPA, the GeoSnap/CHROMA-D allows a simpler overall design for the CARBO instrument
- Snapshot, integrated while read
- Full frame rate: 120 Hz for 2k x 2k





Radiometric Performance Estimate

- The engineering design work is guided by Radiometric performance estimate of signal-to-noise analysis, which is a function of:
  - Radiometry over the band
  - Observational Scenarios (albedo and SZA)
  - Instrument parameters
  - Throughput of the system
  - FPA noise performance
  - Integration time
  - Fabrication constraints



Summary and Conclusion

- CARBO is a tech demo instrument, funded by NASA's Instrument Incubator Program (IIP)
- CARBO is modular with a suite of 4 instruments (758nm, 1628nm, 2062nm, 2327nm)
  - Wide-FOV from LEO at 12 degrees (148 km ground swath)
  - CO_2, CH_4, CO and enhanced SIF measurements
  - 2x2 km^2 spatial resolution
  - 0.05 nm – 0.15 nm spectral resolution
  - Weekly revisit rate
  - Compact design, common form factor, share one platform
- CARBO advances the following key technologies:
  - Immersion gratings
  - Large format FPA, GeoSnap/CHROMA-D
  - Simultaneous polarization sensing
  - Modular architecture, same form factor, on a common platform
- JPL designs, builds and fields instruments 2, and designs instruments 1, 3 and 4